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# RESEARCH MEMORANDUM

for

U. S. Army Ordnance

STATIC LONGITUDINAL STABILITY CHARACTERISTICS OF

A SERIES OF 90-MILLIMETER ARTILLERY SHELLS

AT MACH NUMBERS OF 0.8, 0.9, 1.0, and 1.2

By Stanley H. Spooner

Langley Aeronautical Laboratory  
Langley Field, Va.

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## STATIC LONGITUDINAL STABILITY CHARACTERISTICS OF

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## SUMMARY

Wind-tunnel tests have been made to determine the static longitudinal stability of several models of a short-range artillery shell at Mach numbers of 0.8, 0.9, 1.0, and 1.2.

The results of the tests indicated that the best of the spool-shaped shells was statically stable in pitch at all test Mach numbers for an angle-of-attack range up to about  $10^\circ$ . The best of the finned shells was stable to a maximum angle of attack of about  $6^\circ$ .

The addition of a probe to the nose of the finned shells resulted in increased static longitudinal stability at the highest Mach numbers tested and in a large decrease in the axial-force coefficients at all Mach numbers.

## INTRODUCTION

At the request of the Picatinny Arsenal, U. S. Army Ordnance, models of the T294, 90-millimeter shells were tested to determine the static longitudinal stability characteristics in the transonic speed range. The models were full-size versions of several designs for a short-range shell which is to be fired from a shoulder-mounted, recoilless rifle and is to attain a maximum Mach number of 1.2. The tests were made in the Langley 8-foot transonic pressure tunnel at Mach numbers of 0.8, 0.9, 1.0, and 1.2 through an angle-of-attack range of  $-2^\circ$  to a maximum of  $10^\circ$ .

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## SYMBOLS

The data are referred to a set of axes coinciding with the body axes and originating at the model center of gravity as shown in figure 1.

$C_N$	normal-force coefficient, $\frac{\text{Normal force}}{qA}$
$C_A$	axial-force coefficient, $\frac{\text{Axial force}}{qA}$
$C_m$	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qAD}$
$C_{p,b}$	base pressure coefficient, $\frac{p_b - p_o}{q}$
$q$	dynamic pressure, lb/sq ft
$p_b$	base static pressure, lb/sq ft
$p_o$	free-stream static pressure, lb/sq ft
$A$	cross-sectional area, 0.0685 sq ft
$D$	diameter of 90-millimeter shell, 0.2953 ft
$M$	Mach number
$\alpha$	angle of attack, deg

## MODELS AND TESTS

The models were supplied by the U. S. Army Ordnance and were of aluminum construction. The principal dimensions are shown in figure 1. Some of the shell models were equipped with fins, whereas the others were without fins. The E3-series configurations had identical bodies but the fins differed in length and shape. The cylindrical body of the E1-series configuration was somewhat longer than that of the E3-series configurations. The spool-shaped E4-series had no fins. A blunt-nosed probe was attachable to the nose of the finned shells.

Photographs of one of the models mounted on the balance support sting are shown as figure 2.

The tests were conducted in the Langley 8-foot transonic pressure tunnel. The normal and axial forces and the pitching moments were measured simultaneously by means of an electrical strain-gage balance mounted within the models. The angle of attack was measured by means of an electrical strain-gage pendulum device mounted internally at the base of the support sting. Corrections for the effect of model and sting deflections occurring ahead of the support base were determined from static tests. The static pressures at the base of the models were measured and the axial force was adjusted to the condition of free-stream static pressure at the base.

The models were tested at stream Mach numbers of 0.8, 0.9, 1.0, and 1.2 through an angle-of-attack range extending from  $-2^\circ$  to a maximum of  $10^\circ$ . Because of the large axial forces acting on some model configurations, it was necessary to reduce the tunnel stagnation pressure to about 0.7 atmosphere in order to keep within the load limits of the strain-gage balance. A stagnation pressure of 1 atmosphere was used wherever an angle of attack of  $6^\circ$  or greater could be obtained without exceeding the balance limits. The variation of Reynolds number per foot of reference length with Mach number is shown in figure 3.

Jet boundary and blockage corrections are negligible and have not been applied to the data. At the Mach numbers for which the data are presented, the effects of the boundary-reflected disturbances are also negligible.

#### ACCURACY

The average stream Mach number is estimated to be accurate within  $\pm 0.003$ . The estimated accuracy of the angle of attack and the coefficients is as follows:

$\alpha$ , deg . . . . .	$\pm 0.1$
$C_m$ . . . . .	$\pm 0.010$
$C_N$ . . . . .	$\pm 0.020$
$C_A$ . . . . .	$\pm 0.010$
$C_{p,b}$ . . . . .	$\pm 0.004$

## RESULTS AND DISCUSSION

The normal-force and pitching-moment characteristics of the several model configurations are shown in figures 4 to 15. The axial-force characteristics are shown in figures 16 to 21. The base pressure coefficients are presented in table I.

## Pitch Characteristics

With the exception of configurations E1A and E4, all models had stable pitching-moment characteristics at all test Mach numbers up to an angle of attack of about  $4^\circ$ . Configuration E1A (fig. 12) was unstable up to at least  $2^\circ$  angle of attack at Mach numbers of 0.9, 1.0, and 1.2. Configuration E4 (fig. 13) was unstable to  $6^\circ$  at Mach numbers of 1.0 and 1.2.

Configuration E4B (fig. 15) was stable at all test Mach numbers and at all angles of attack up to about  $10^\circ$ , the highest angle investigated. Configuration E4A (fig. 14) and the E3-series finned shells with probe (figs. 5, 7, 9, and 11) were stable to about  $6^\circ$ .

Removal of the probe from the finned shells resulted in decreased stability at some or all Mach numbers. Furthermore, a double set of data was obtained from tests of several configurations not having the probe. In normal test procedure, the angle of attack of a model is varied in increments from a given angle to a higher angle. However, for some of the shell configurations, the angle of attack was also varied in the opposite sequence; that is, the angle was varied in increments from high to low values since, during the test, visual inspection of the data indicated certain differences from those obtained in the normal manner. The data obtained in this manner are indicated in the figures by dashed lines. The different results obtained may have resulted from flow separation which, once it occurred, required a somewhat lower angle of attack for reattachment. In addition to the E3-series finned shells without probe, configuration E4 also exhibited similar characteristics.

Above a Mach number of 0.9, the stability of the finned shells generally decreased with an increase in Mach number, whereas for configurations E4A and E4B, at small angles of attack, the stability increased.

## Force Characteristics

Normal force.— For the finned shell configurations with the probe, the normal-force coefficient increased more or less linearly with angle of attack. Without the probe and at Mach numbers of 0.8 and 0.9, however,

the normal-force coefficient decreased with increased angle of attack up to  $2^{\circ}$  or  $3^{\circ}$ , at which point it began to increase with further increase in angle of attack.

The spool-shaped shells, which did not have probes, exhibited normal-force characteristics similar to those of the finned shells without probes.

The effect of direction of approach to a given angle of attack is also shown in the normal-force coefficients for the same configurations as those whose pitching-moment coefficients were affected.

Axial force.- For the configurations with the probe, the axial-force coefficients increased rapidly with angle of attack; whereas, without the probe, there was only a comparatively small variation, if any, with angle of attack. There was a large increase in the axial-force coefficient between Mach numbers of 0.9 and 1.0 for configurations with the probe. Without the probe, however, the increase with Mach number was in roughly constant increments from Mach number 0.8 to 1.2. Although minimum values of axial-force coefficient varied somewhat with the configuration, the addition of the probe resulted in large decreases in the minimum values.

Configuration E4B, which had the lowest minimum axial-force coefficients of all configurations without the probe, probably would compare favorably also, if a probe were added, with the other probe-on configurations.

#### CONCLUDING REMARKS

The results of tests of a number of configurations of the T294, 90-millimeter shells in the Langley 8-foot transonic pressure tunnel at Mach numbers of 0.8, 0.9, 1.0, and 1.2 indicate that the pitch characteristics of the E4-series spool-shaped shells are superior to those of either the E1 or E3-series finned shells. Only configuration E4B is longitudinally stable for all test Mach numbers up to an angle of attack of about  $10^{\circ}$ , the maximum angle tested. The best of the finned shells is stable to about  $6^{\circ}$ .

The addition of the probe to the finned shells resulted in a large decrease in the axial-force coefficient at all Mach numbers and also resulted in increased stability at the highest Mach numbers. It is

suggested that the addition of a probe to the E4-series shells would result in considerable reduction of axial-force coefficient.

Langley Aeronautical Laboratory,  
National Advisory Committee for Aeronautics,  
Langley Field, Va., April 10, 1956.

*Stanley H. Spooner*

Stanley H. Spooner  
Aeronautical Research Scientist

Approved:

*Eugene C. Draley*

Eugene C. Draley  
Chief of Full-Scale Research Division

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TABLE I.- BASE PRESSURE COEFFICIENTS  $C_{p,b}$ 

$M \backslash \alpha, \text{ deg}$	-2	0	2	4	6	8	10
E3 without probe							
0.8	-0.045	-0.040	-0.046	-0.024	-0.021	-0.042	-0.077
.9	-.118	-.120	-.124	-.090	-.104	-.166	-.242
1.0	-.160	-.188	-.171	-.162	-.192	-.245	-.307
1.2	-.195	-.185	-.193	-.200	-.191	-.213	-.267
E3 with probe							
0.8	-0.073	-0.067	-0.068	-0.074	-0.084	-0.097	-0.110
.9	-.075	-.072	-.070	-.073	-.088	-.104	-.110
1.0	-.201	-.192	-.193	-.203	-.235	-.264	-.277
1.2	-.214	-.209	-.210	-.222	-.255	-.301	-----
E3A without probe							
0.8	-0.075	-0.073	-0.079	-0.092	-0.056	-0.059	-0.092
.9	-.165	-.164	-.167	-.176	-.192	-.237	-.295
1.0	-.184	-.180	-.181	-.188	-.205	-.249	-.323
1.2	-.195	-.185	-.190	-.212	-.246	-.287	-.305
E3A with probe							
0.8	-0.060	-0.060	-0.062	-0.071	-0.083	-0.097	-0.110
.9	-.063	-.060	-.062	-.072	-.090	-.107	-.116
1.0	-.208	-.200	-.202	-.218	-.249	-.278	-.294
1.2	-.216	-.209	-.212	-.225	-.257	-.296	-.313
E3B without probe							
0.8	-0.076	-0.075	-0.073	-0.070	-0.050	-0.058	-0.078
.9	-.154	-.159	-.160	-.126	-.121	-.155	-.257
1.0	-.191	-.212	-.197	-.173	-.193	-.264	-.324
1.2	-.200	-.195	-.198	-.211	-.235	-.266	-.305
E3B with probe							
0.8	-0.062	-0.058	-0.063	-0.072	-0.083	-0.094	-----
.9	-.064	-.060	-.062	-.071	-.087	-.100	-----
1.0	-.205	-.204	-.206	-.217	-.243	-.266	-----
1.2	-.222	-.219	-.221	-.233	-.255	-.285	-.300
E3C without probe							
0.8	-0.160	-0.152	-0.162	-0.124	-0.095	-0.089	-0.107
.9	-.246	-.255	-.251	-.258	-.217	-.230	-----
1.0	-.188	-.188	-.195	-.208	-----	-----	-----
1.2	-----	-----	-----	-----	-----	-----	-----
E3C with probe							
0.8	-0.041	-0.040	-0.044	-0.054	-0.065	-0.076	-0.085
.9	-.033	-.031	-.037	-.051	-.069	-.080	-.083
1.0	-.183	-.182	-.183	-.202	-.232	-.269	-----
1.2	-.191	-.186	-.190	-.207	-.236	-.274	-----
E4A with probe							
0.8	-0.027	-0.025	-0.028	-0.035	-0.044	-0.057	-0.070
.9	-.012	-.010	-.011	-.017	-.028	-.044	-.053
1.0	-.063	-.062	-.067	-.078	-.097	-.127	-.161
1.2	-.132	-.129	-.136	-.148	-.165	-.185	-.213
E4 without probe							
0.8	-0.023	-0.018	-0.023	-0.053	-0.113	-0.166	-0.209
.9	-.071	-.099	-.077	-.077	-.110	-.150	-.195
1.0	-.279	-.262	-.272	-.298	-.335	-.378	-.428
1.2	-.274	-.270	-.271	-.287	-.321	-----	-----
E4A without probe							
0.8	0.004	0.020	0.006	-0.034	-0.092	-0.129	-0.167
.9	-.039	-.035	-.041	-.056	-.091	-.133	-.162
1.0	-.205	-.185	-.200	-.245	-.303	-.358	-.257
1.2	-.208	-.189	-.209	-.255	-.304	-.340	-----
E4B without probe							
0.8	-0.021	-0.022	-0.023	-0.040	-0.073	-0.128	-0.166
.9	-.100	-.115	-.097	-.094	-.110	-.148	-.199
1.0	-.215	-.201	-.212	-.256	-.307	-.360	-.403
1.2	-.208	-.182	-.206	-.242	-.290	-.333	-.375



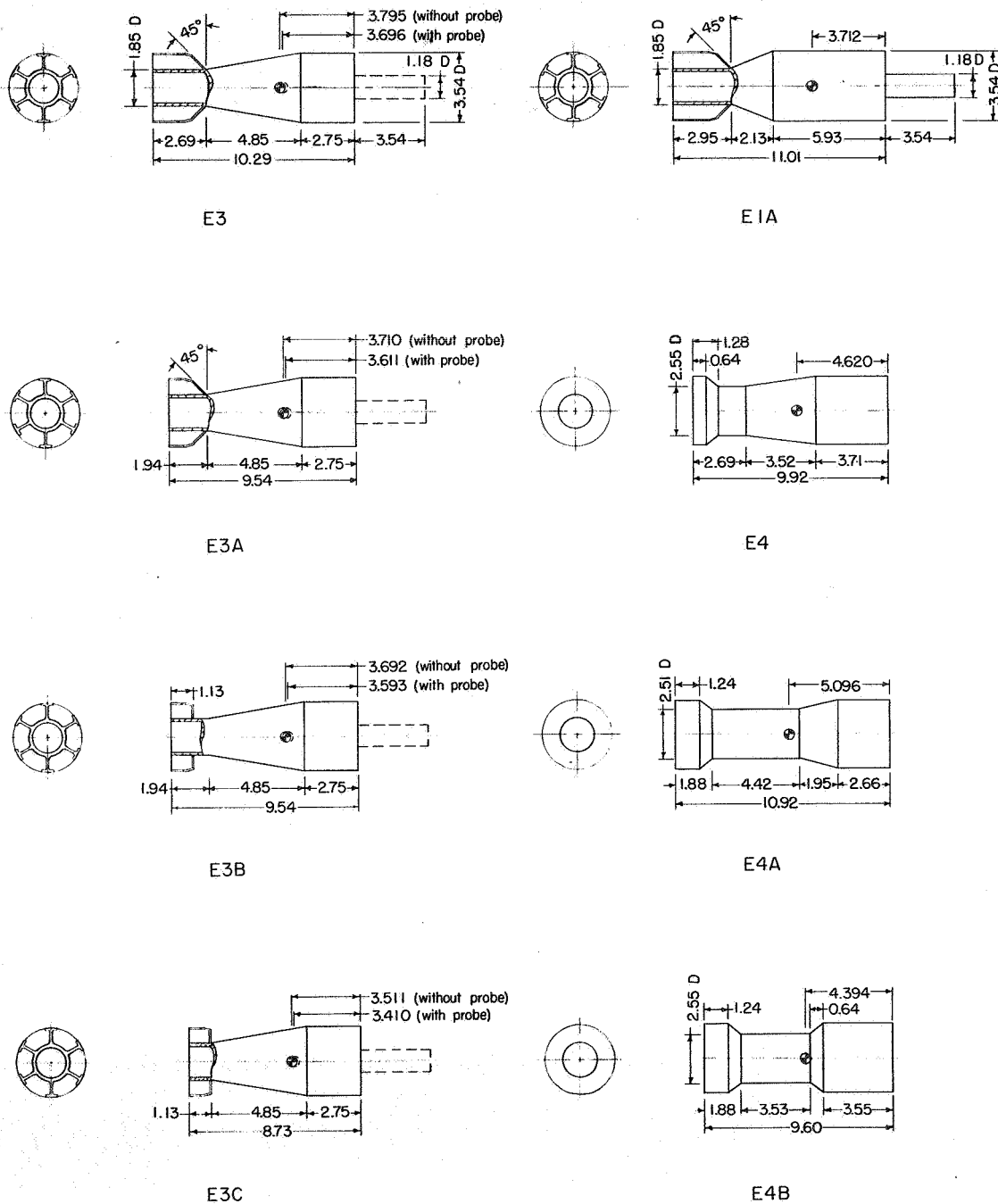
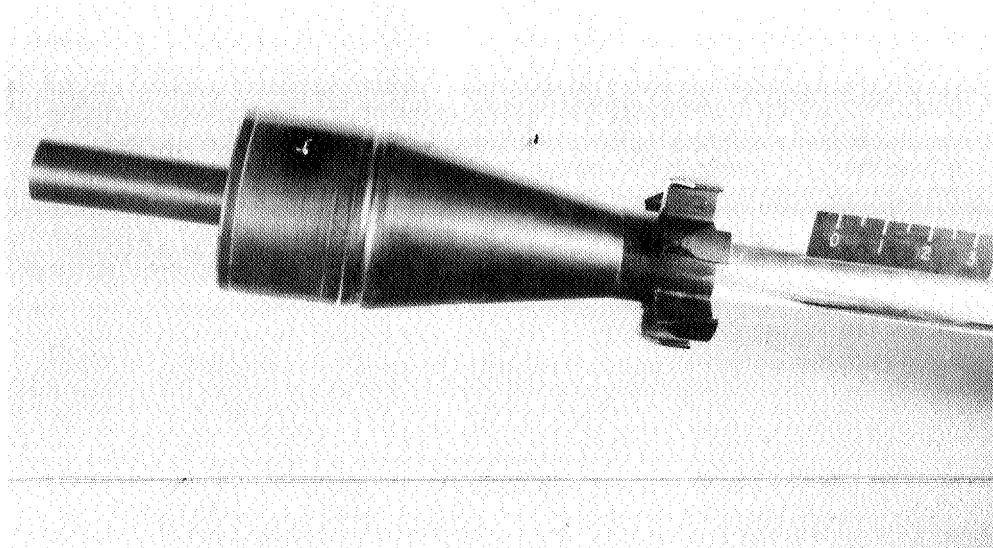
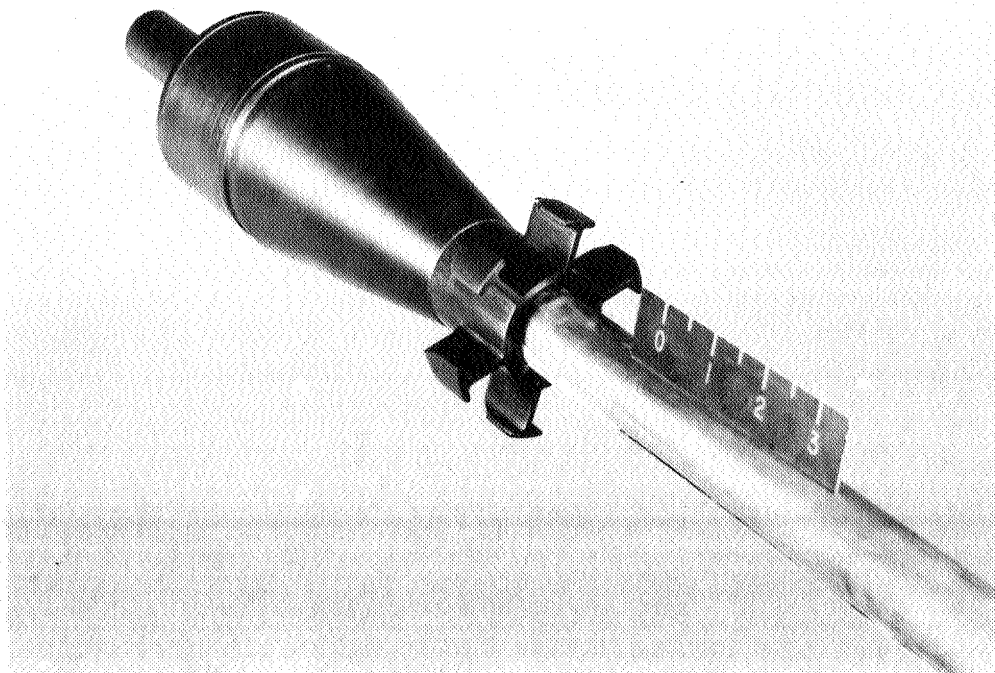


Figure 1.- Various configurations of the T294, 90-millimeter shells. All dimensions in inches.



(a) Side view.

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(b) Rear view.

L-91443

Figure 2.- Photographs of configuration E3B with probe mounted on the support sting.

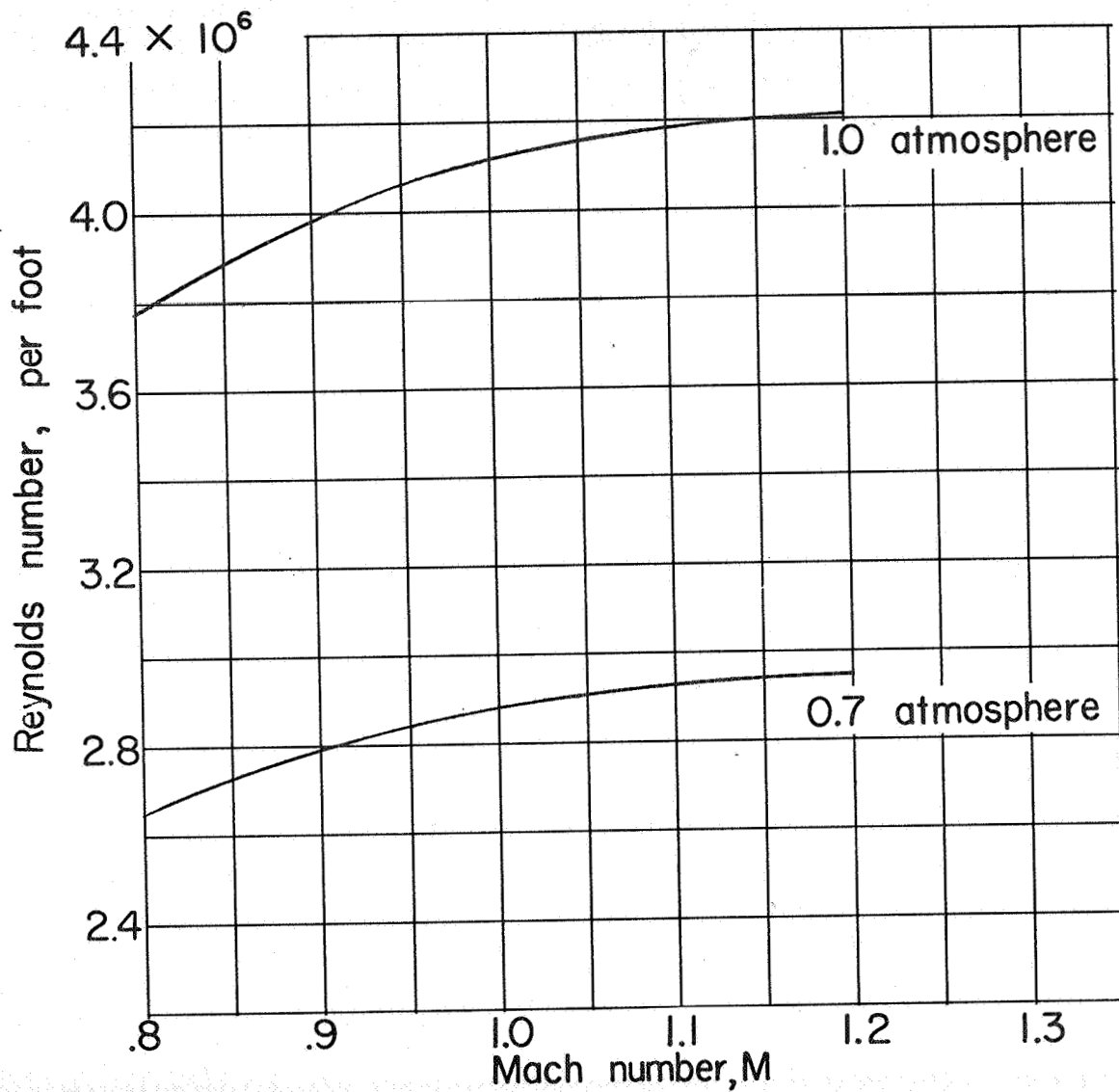
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Figure 3.- Variation of Reynolds number per foot of reference length with Mach number in the Langley 8-foot transonic pressure tunnel.

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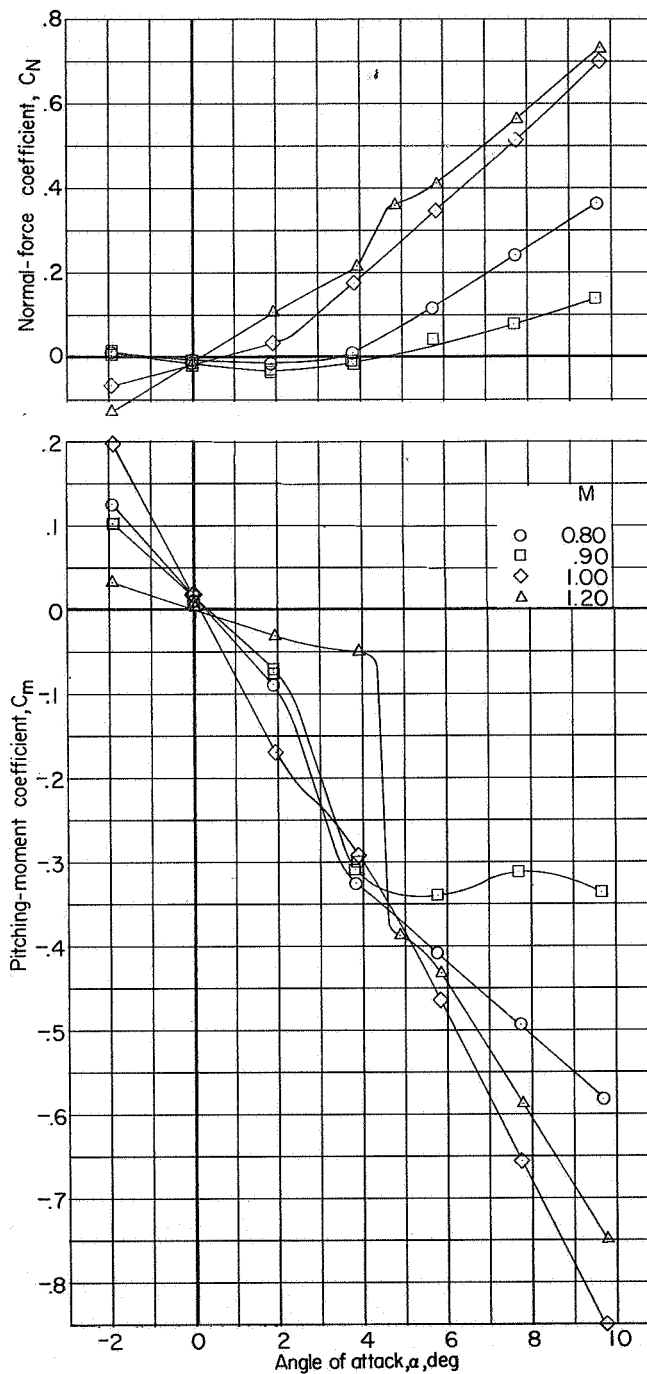


Figure 4.- Variation with angle of attack of pitching-moment and normal-force coefficients for model configuration E3 without probe. Stagnation pressure is approximately 0.7 atmosphere.



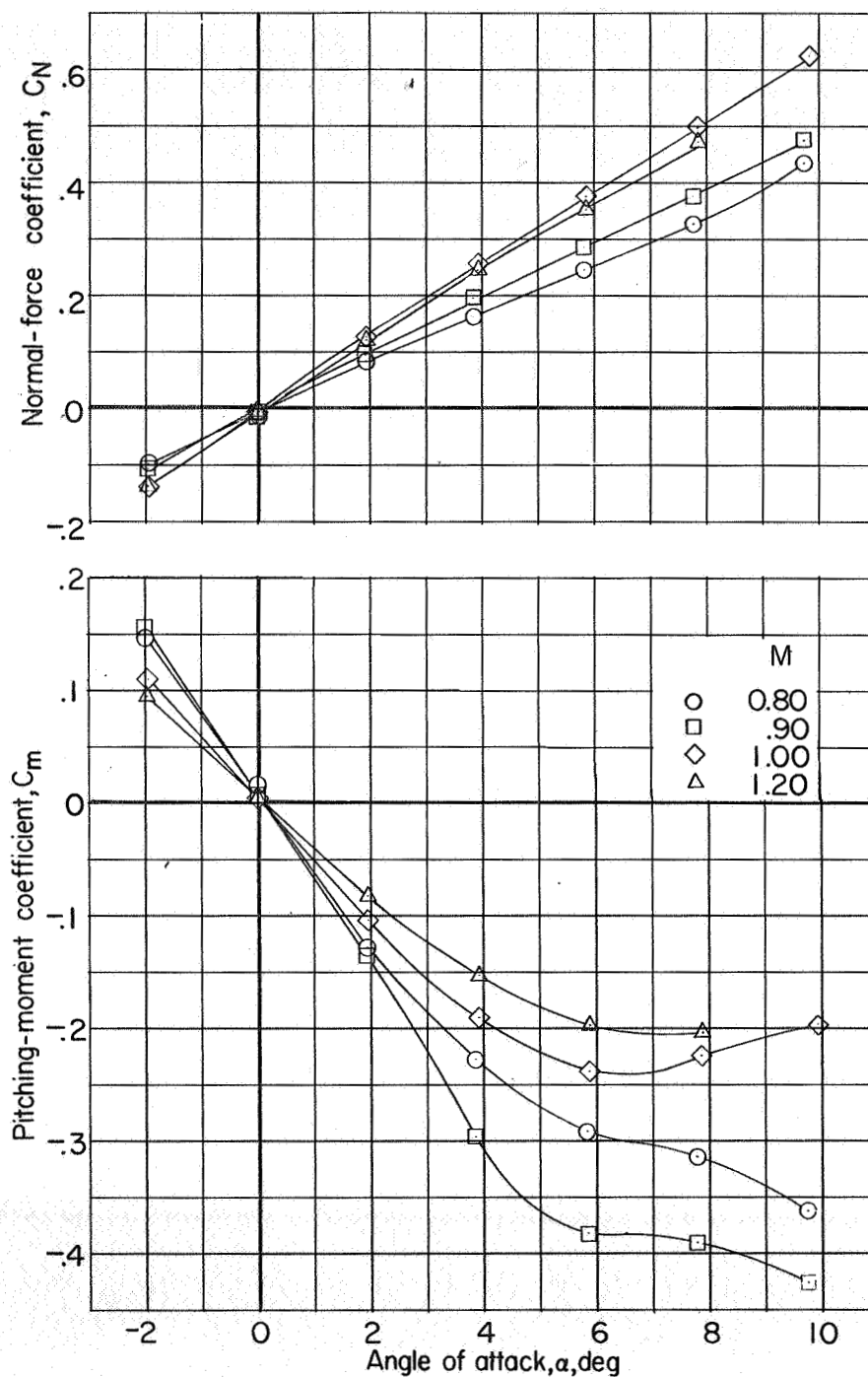


Figure 5.- Variation with angle of attack of pitching-moment and normal-force coefficients for model configuration E3 with probe. Stagnation pressure is approximately 1.0 atmosphere.

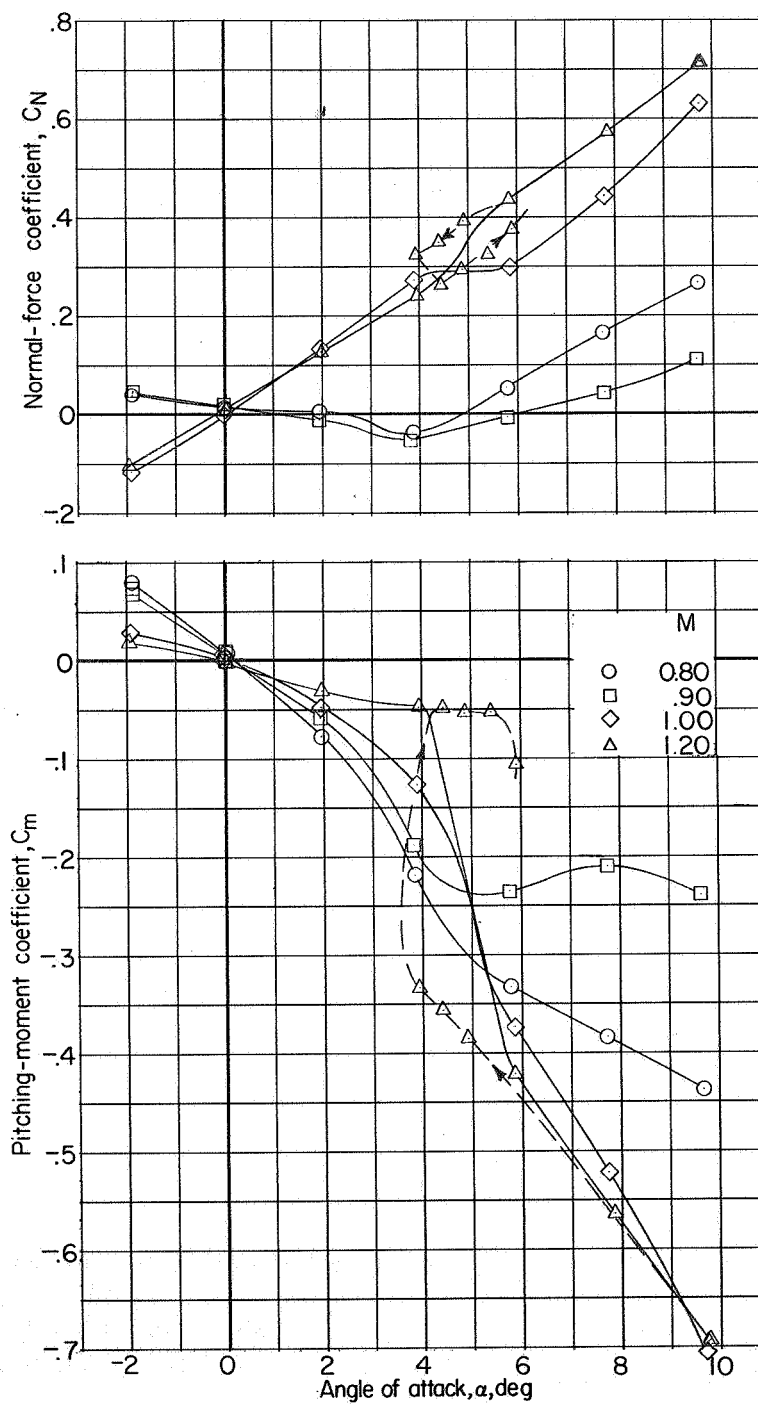


Figure 6.- Variation with angle of attack of pitching-moment and normal-force coefficients for model configuration E3A without probe. Stagnation pressure is approximately 0.7 atmosphere.

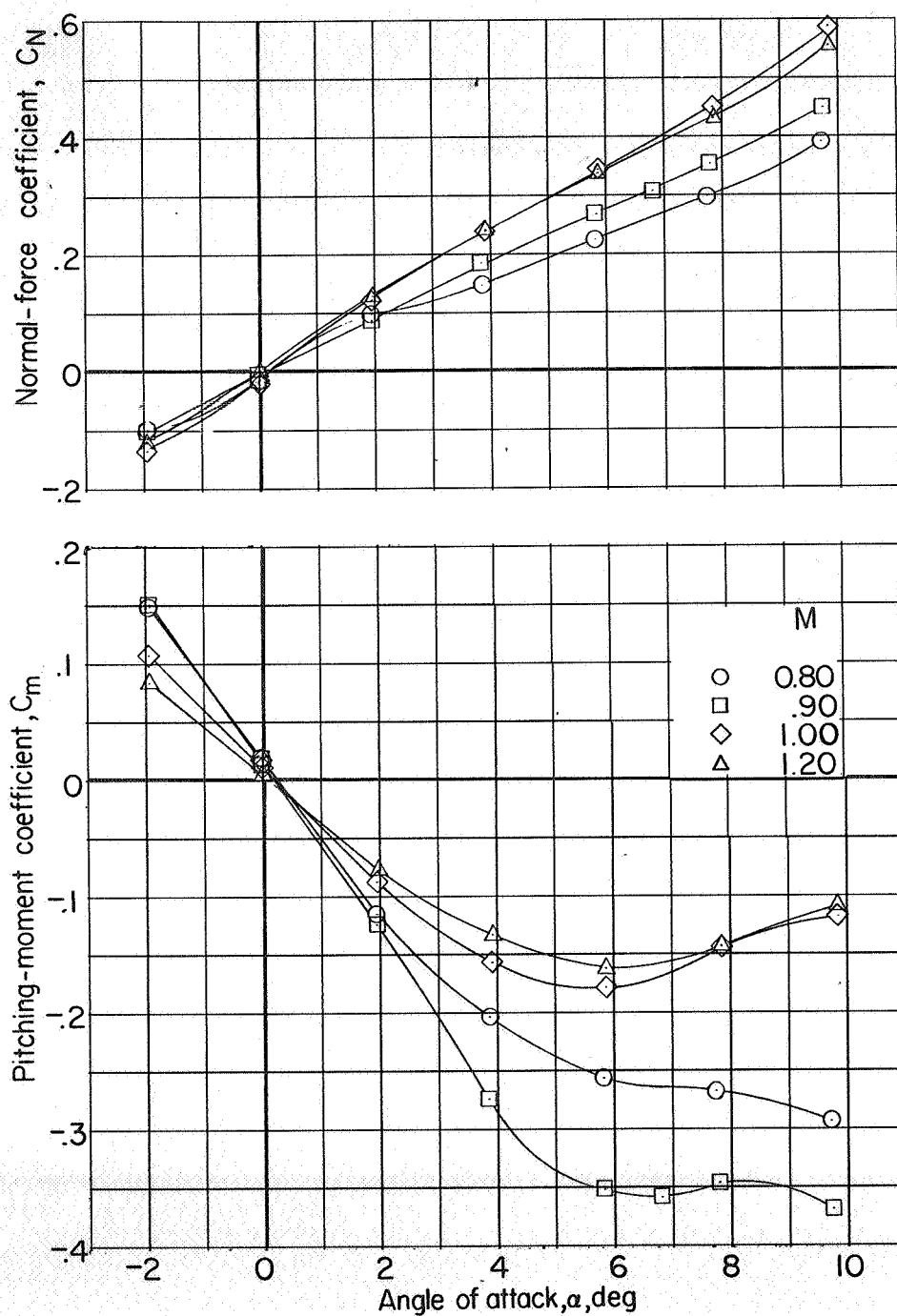


Figure 7.- Variation with angle of attack of pitching-moment and normal-force coefficients for model configuration E3A with probe. Stagnation pressure is approximately 1.0 atmosphere.

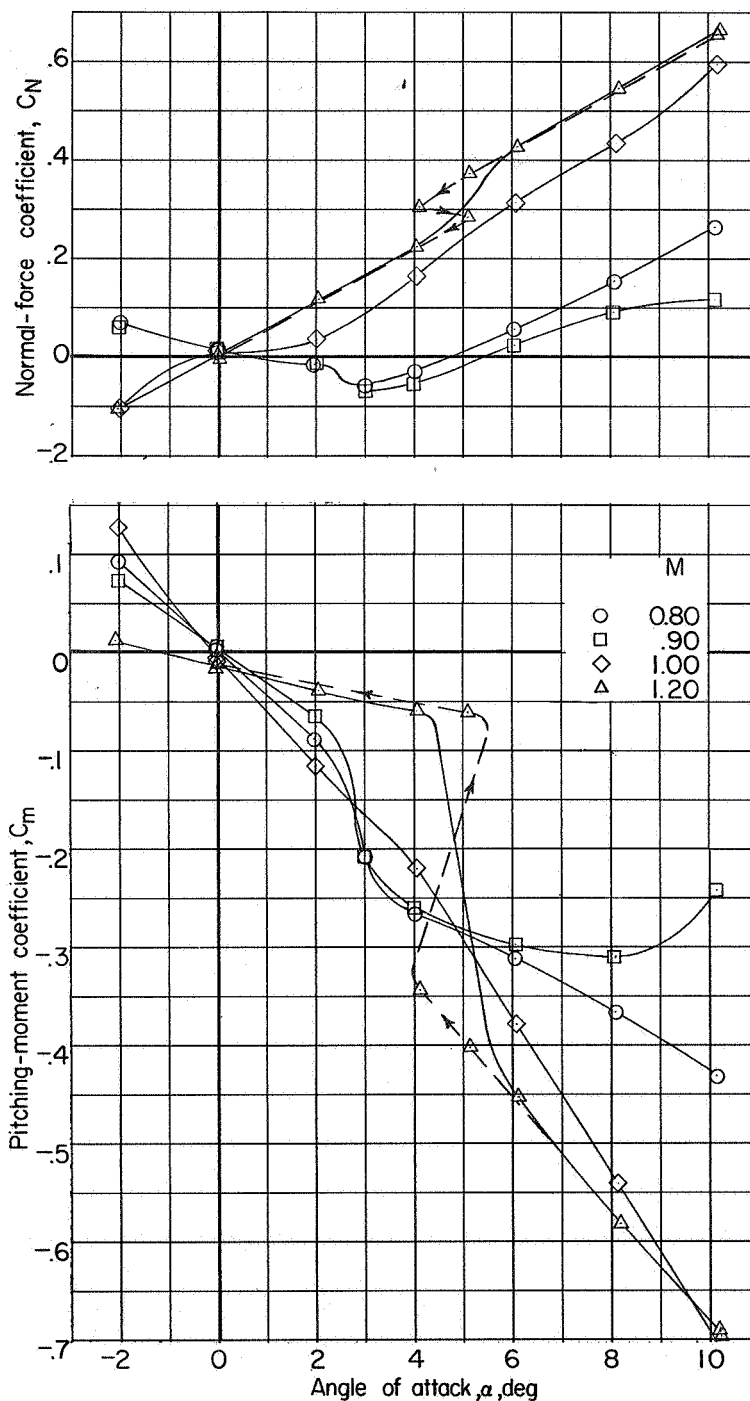
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Figure 8.- Variation with angle of attack of pitching-moment and normal-force coefficients for model configuration E3B without probe. Stagnation pressure is approximately 0.7 atmosphere.

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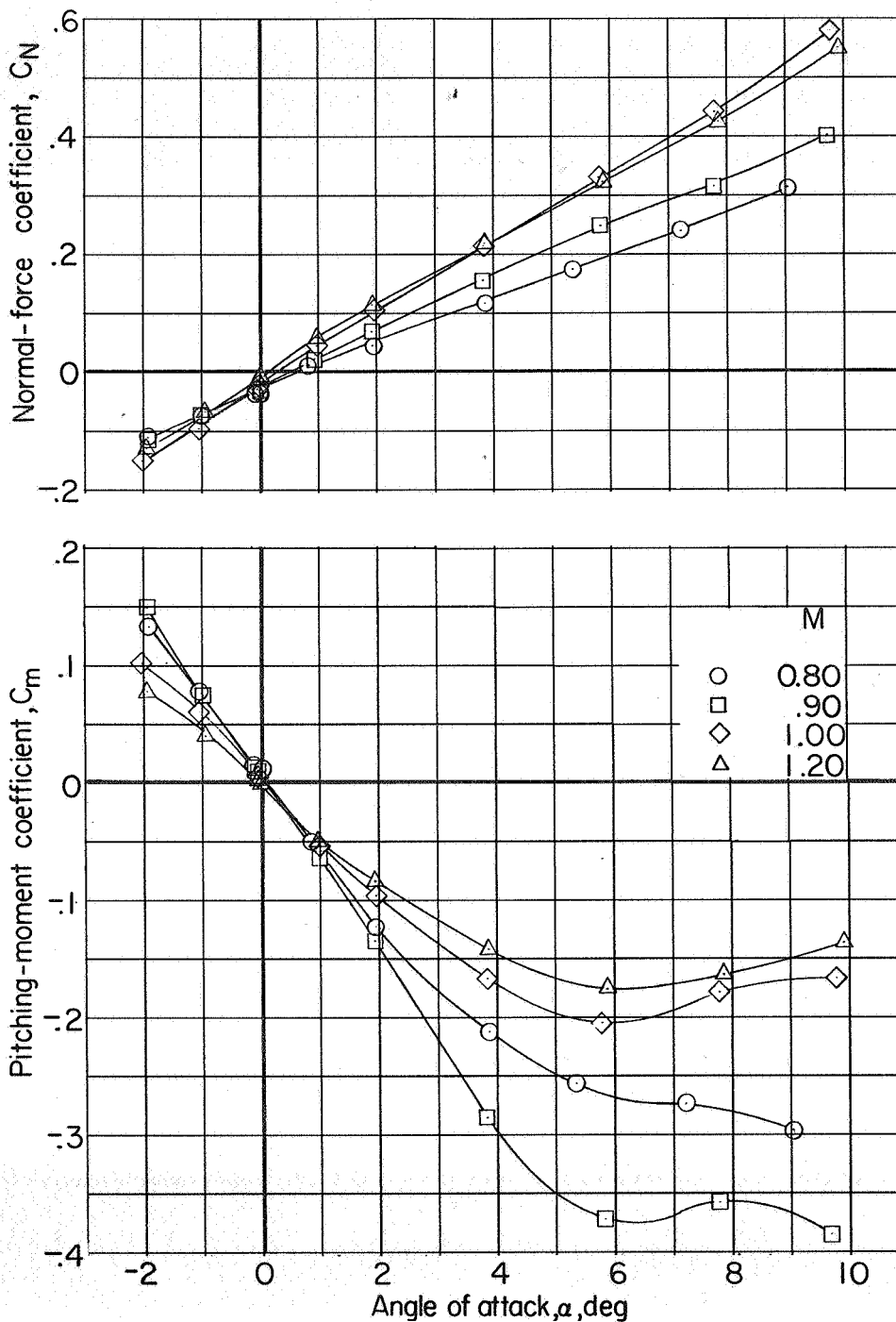


Figure 9.- Variation with angle of attack of pitching-moment and normal-force coefficients for model configuration E3B with probe. Stagnation pressure is approximately 1.0 atmosphere.

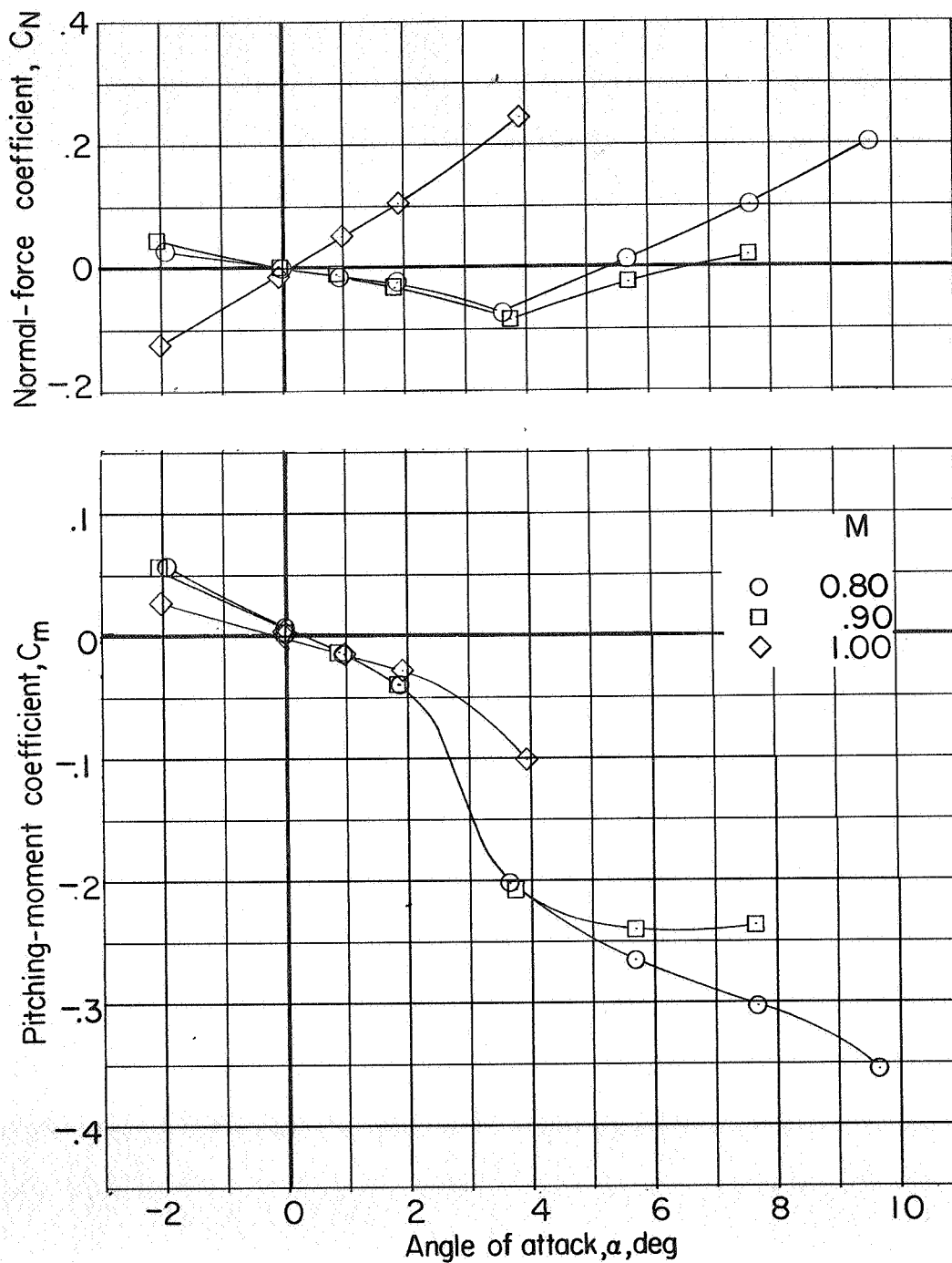
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Figure 10.- Variation with angle of attack of pitching-moment and normal-force coefficients for model configuration E3C without probe. Stagnation pressure is approximately 1.0 atmosphere.

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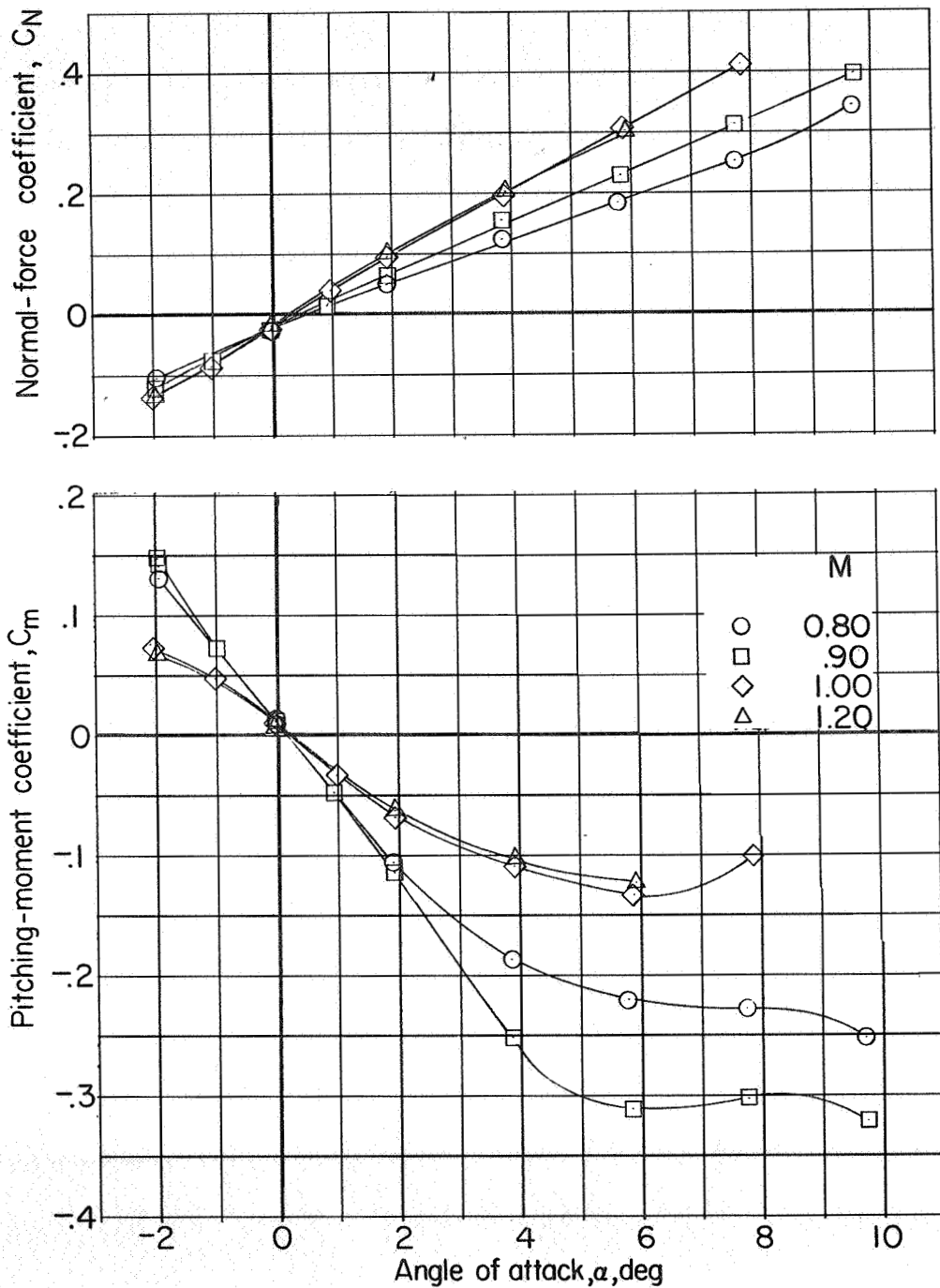


Figure 11.- Variation with angle of attack of pitching-moment and normal-force coefficients for model configuration E3C with probe. Stagnation pressure is approximately 1.0 atmosphere.

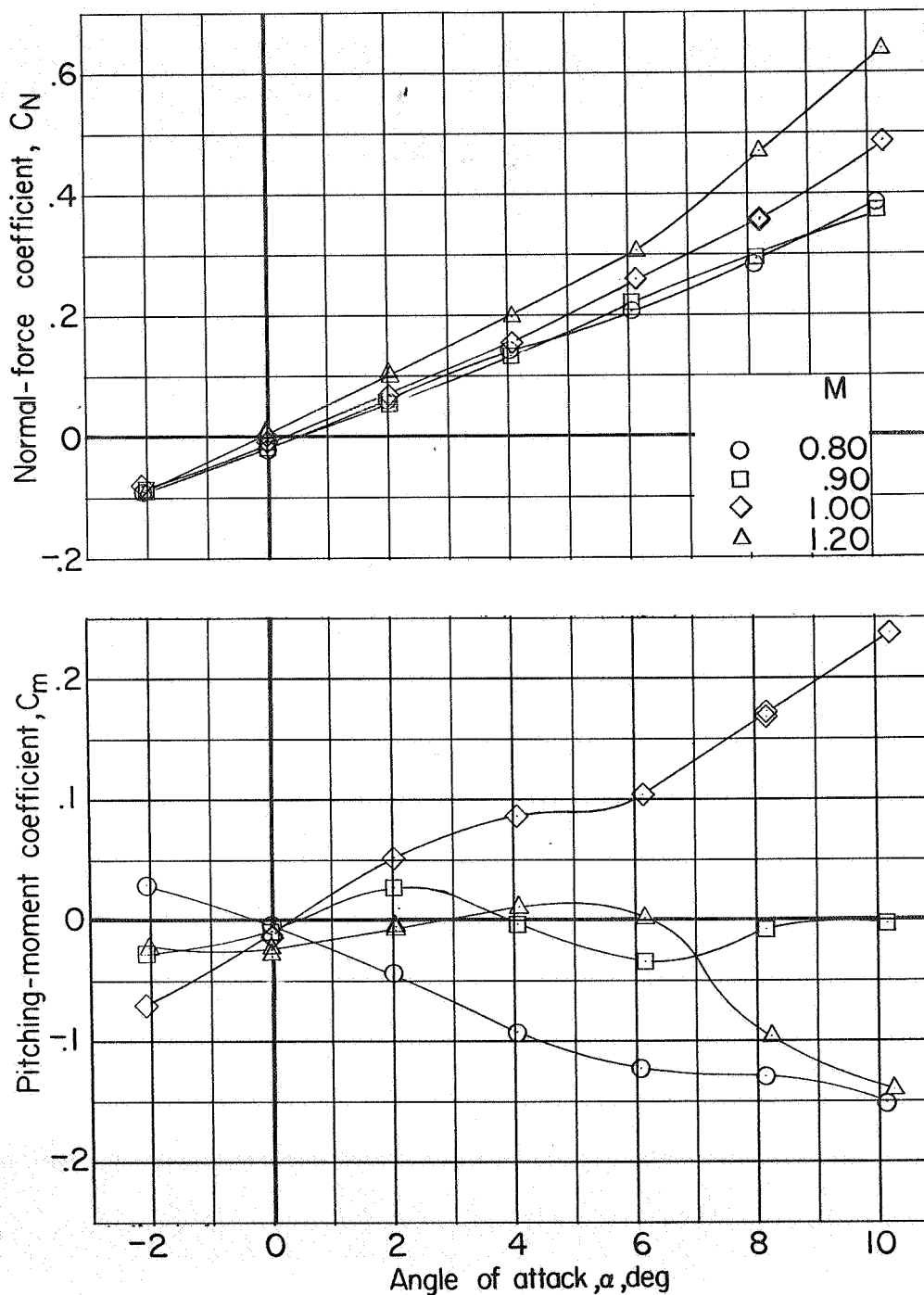


Figure 12.- Variation with angle of attack of pitching-moment and normal-force coefficients for model configuration E1A with probe. Stagnation pressure is approximately 1.0 atmosphere.



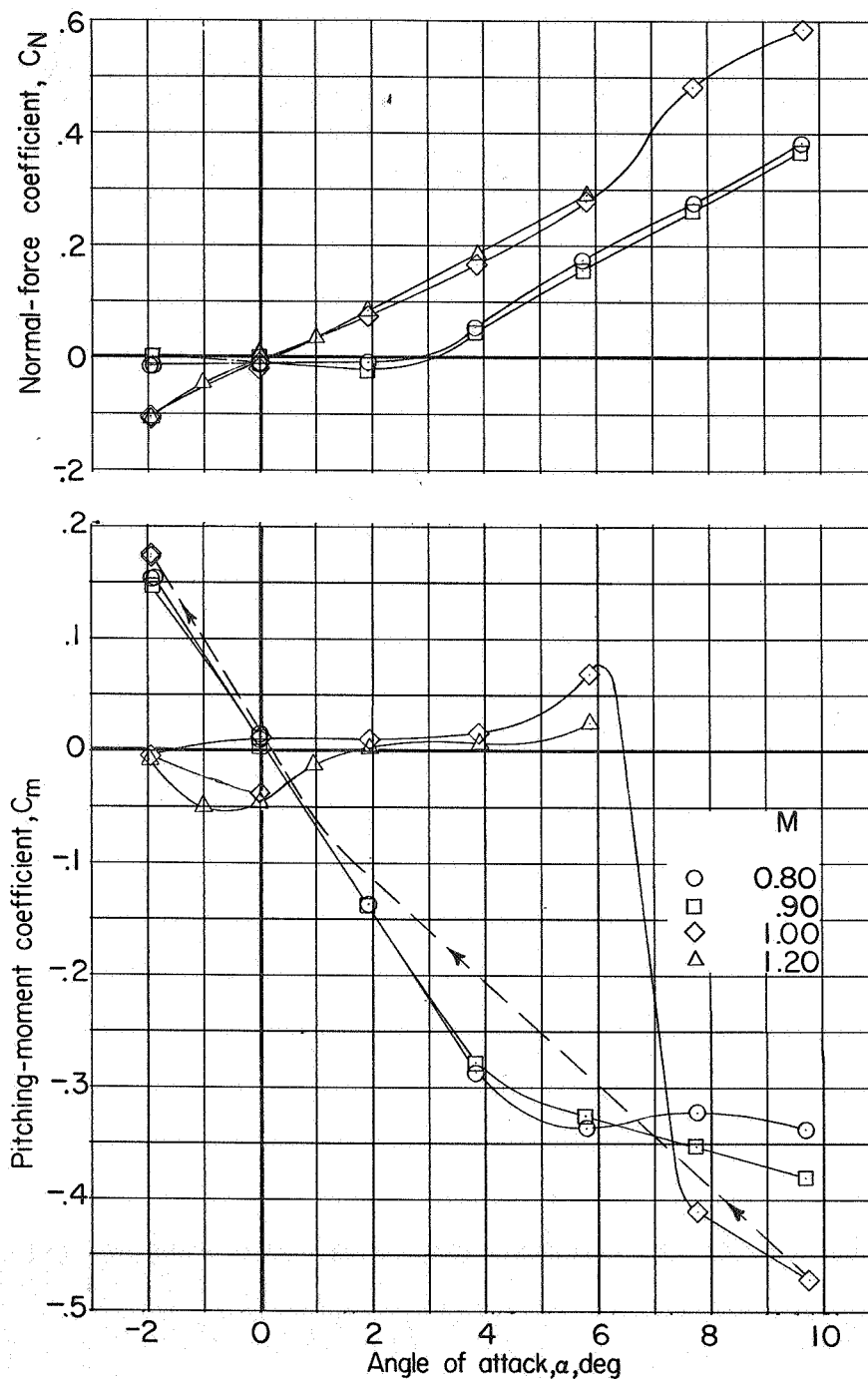


Figure 13.- Variation with angle of attack of pitching-moment and normal-force coefficients for model configuration E4 without probe. Stagnation pressure is approximately 0.7 atmosphere.

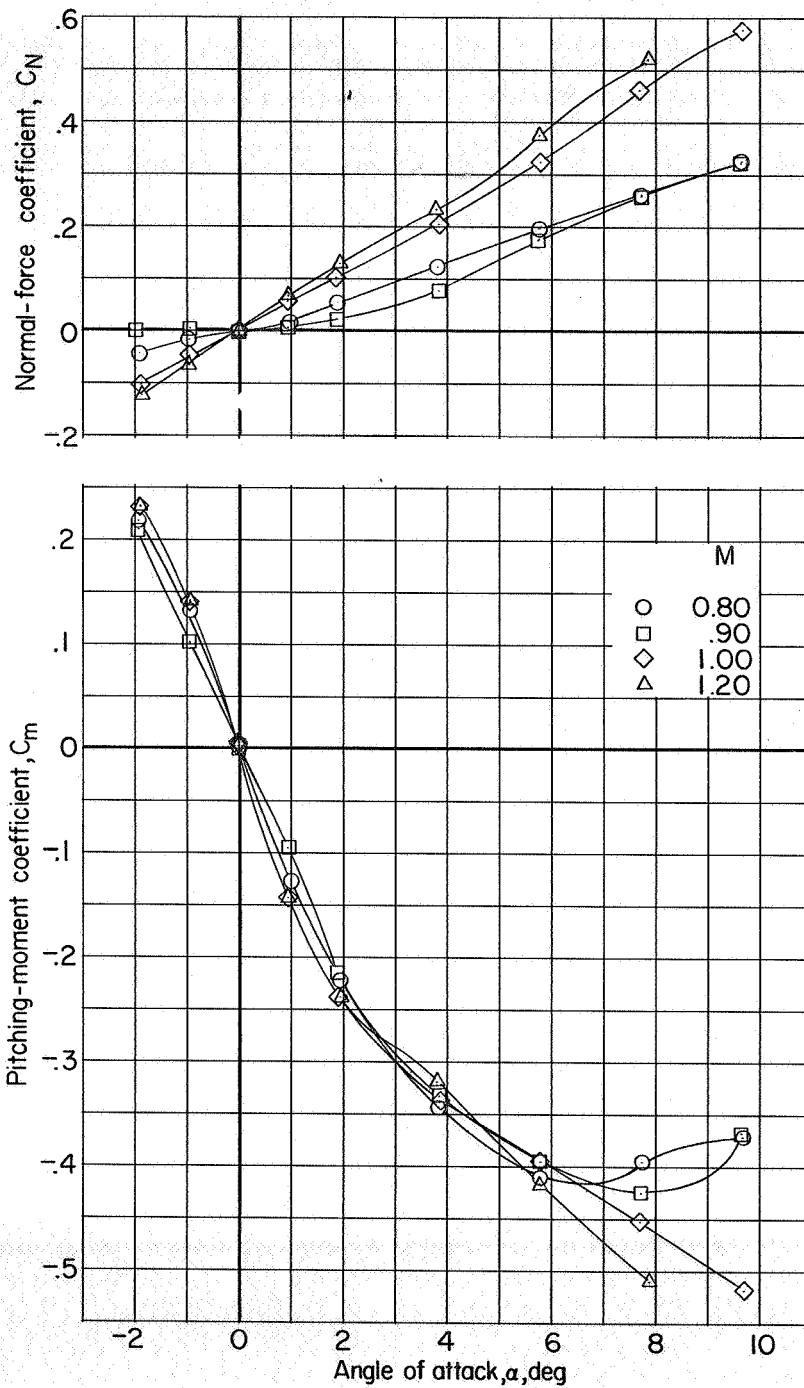


Figure 14.- Variation with angle of attack of pitching-moment and normal-force coefficients for model configuration E4A without probe. Stagnation pressure is approximately 0.7 atmosphere.

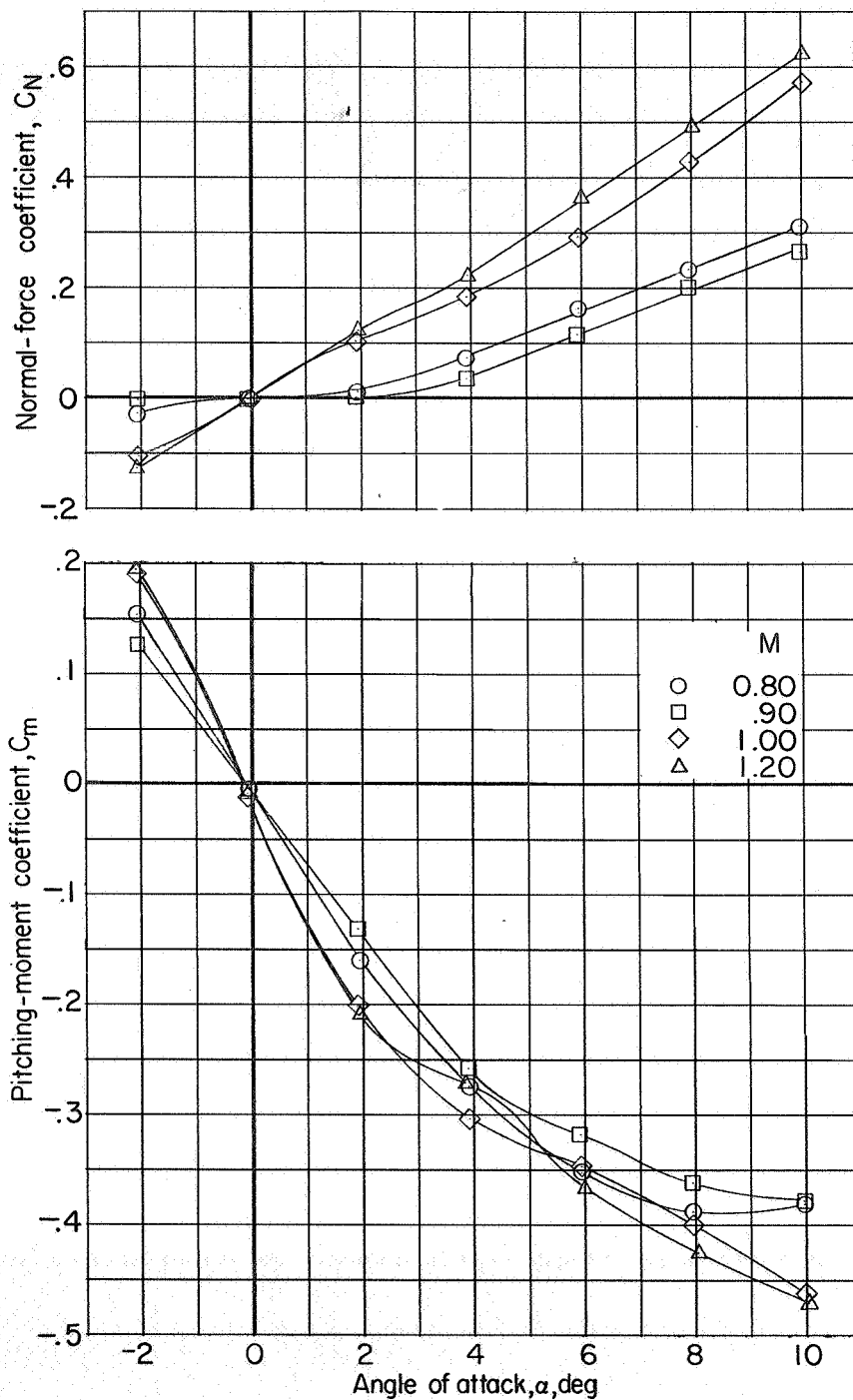


Figure 15.- Variation with angle of attack of pitching-moment and normal-force coefficients for model configuration E4B without probe. Stagnation pressure is approximately 0.7 atmosphere.

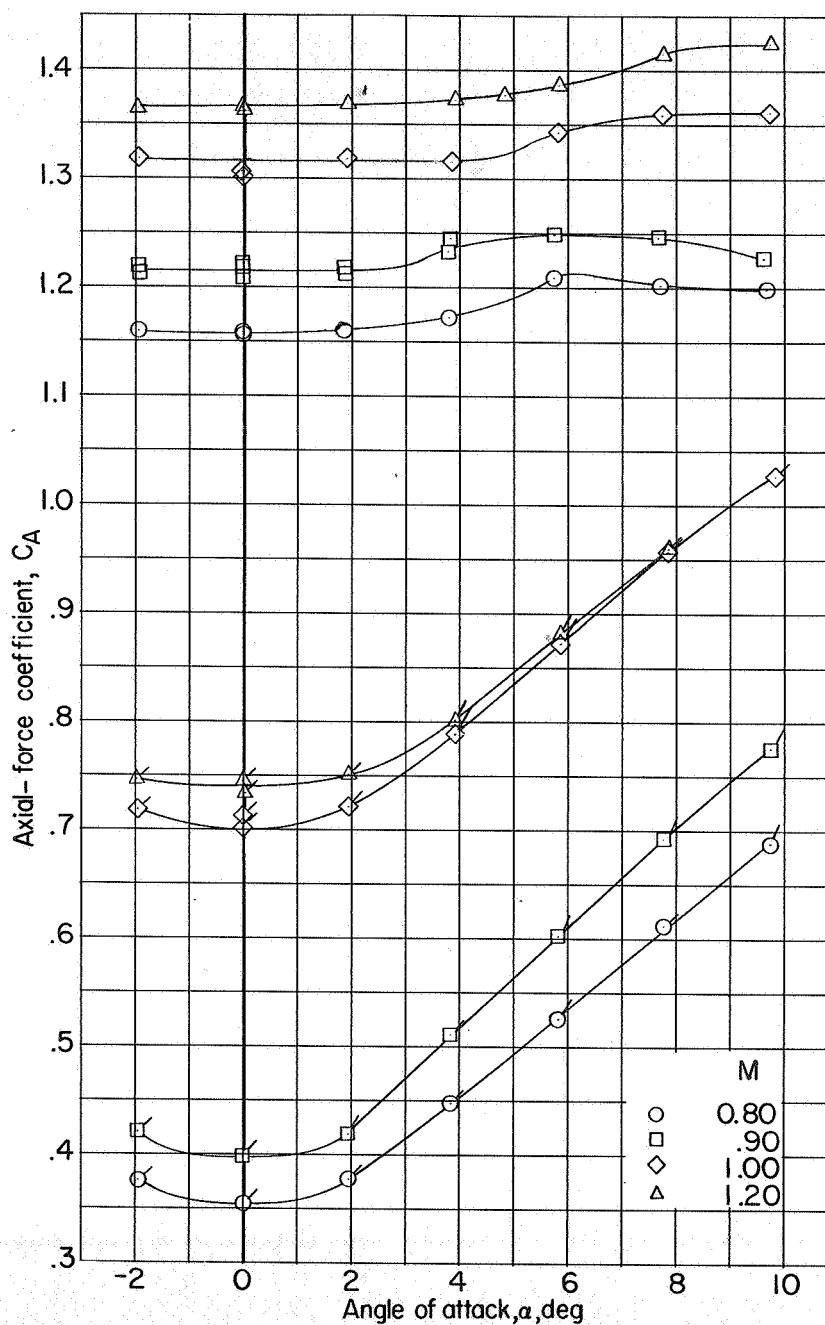


Figure 16.- Variation with angle of attack of axial-force coefficient for model configuration E3 with and without probe. Plain symbols indicate data for model without probe, stagnation pressure is approximately 0.7 atmosphere; flagged symbols, model with probe, stagnation pressure is approximately 1.0 atmosphere.



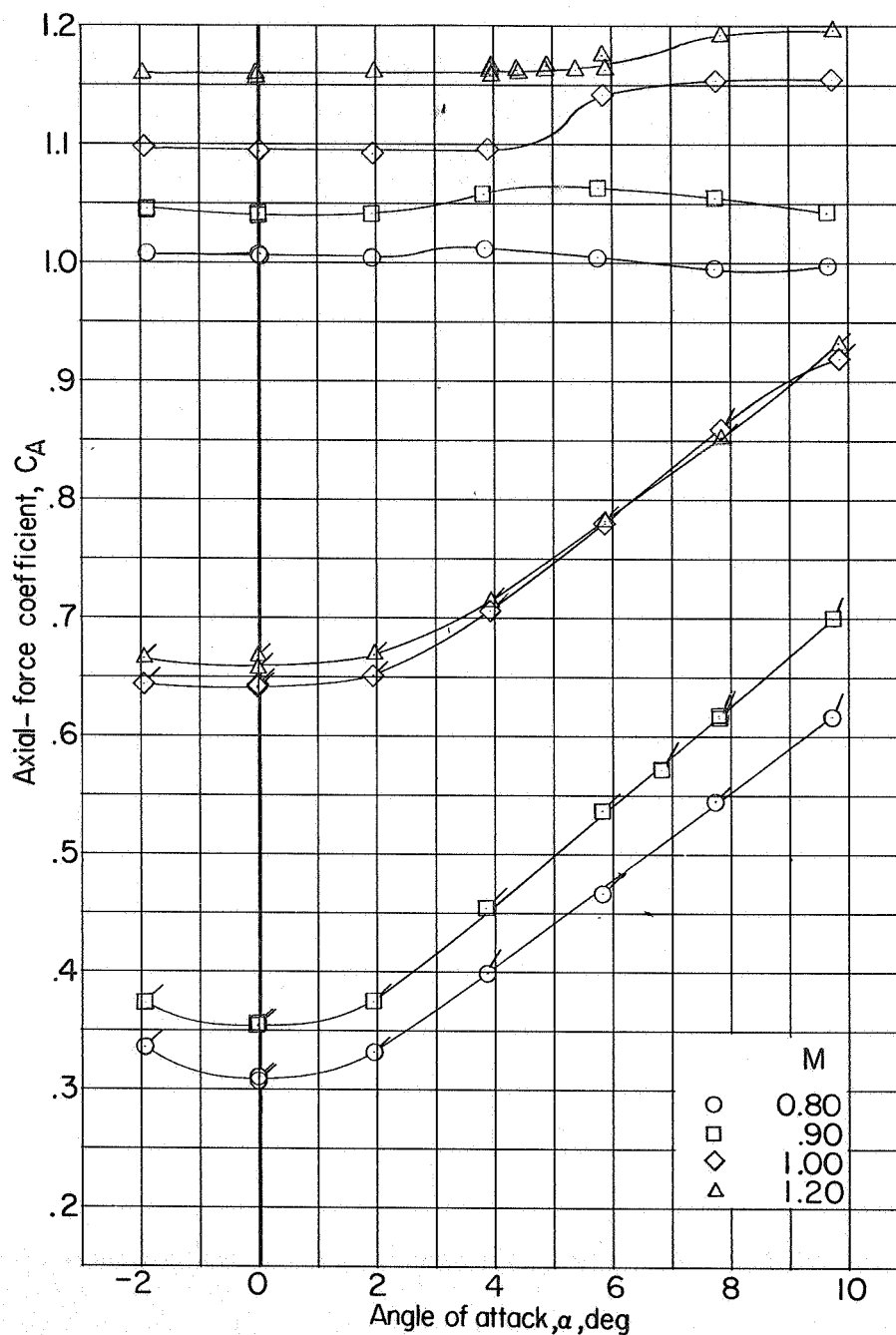


Figure 17.- Variation with angle of attack of axial-force coefficient for model configuration E3A with and without probe. Plain symbols indicate data for model without probe, stagnation pressure is approximately 0.7 atmosphere; flagged symbols, model with probe, stagnation pressure is approximately 1.0 atmosphere.

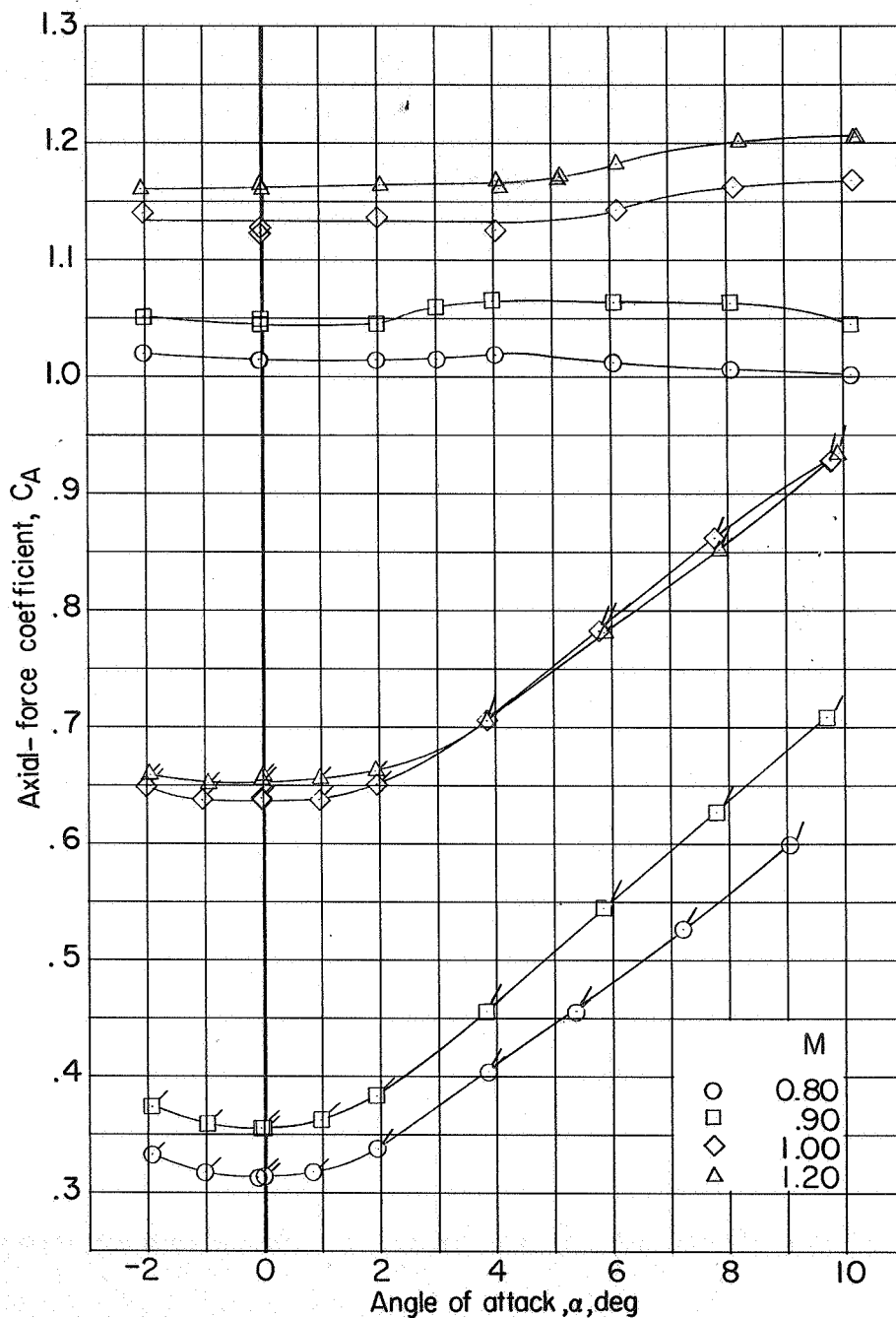


Figure 18.- Variation with angle of attack of axial-force coefficient for model configuration E3B with and without probe. Plain symbols indicate data for model without probe, stagnation pressure is approximately 0.7 atmosphere; flagged symbols, model with probe, stagnation pressure is approximately 1.0 atmosphere.

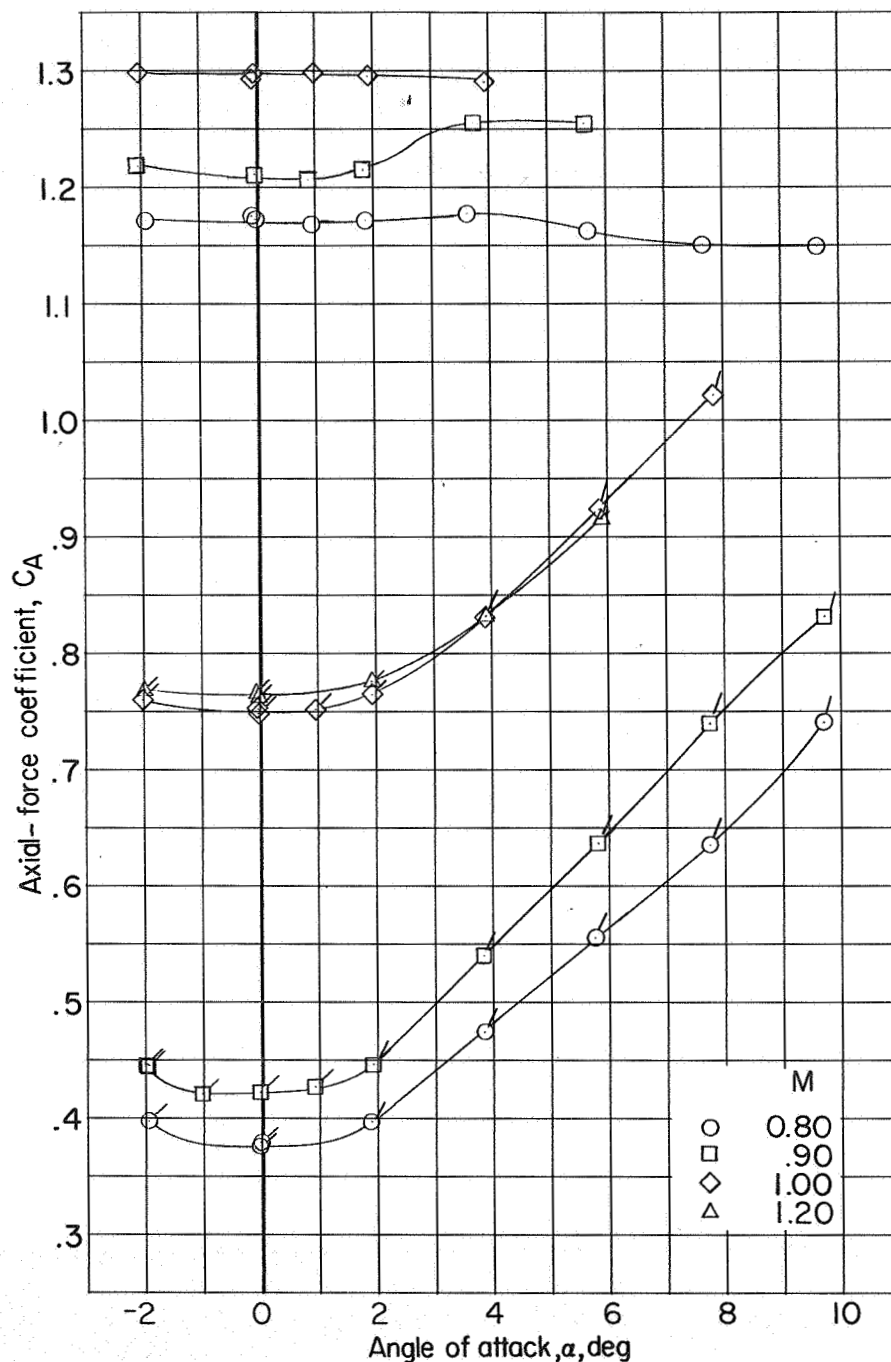


Figure 19.- Variation with angle of attack of axial-force coefficient for model configuration E3C with and without probe. Plain symbols indicate data for model without probe; flagged symbols, model with probe. Stagnation pressure is approximately 1.0 atmosphere.

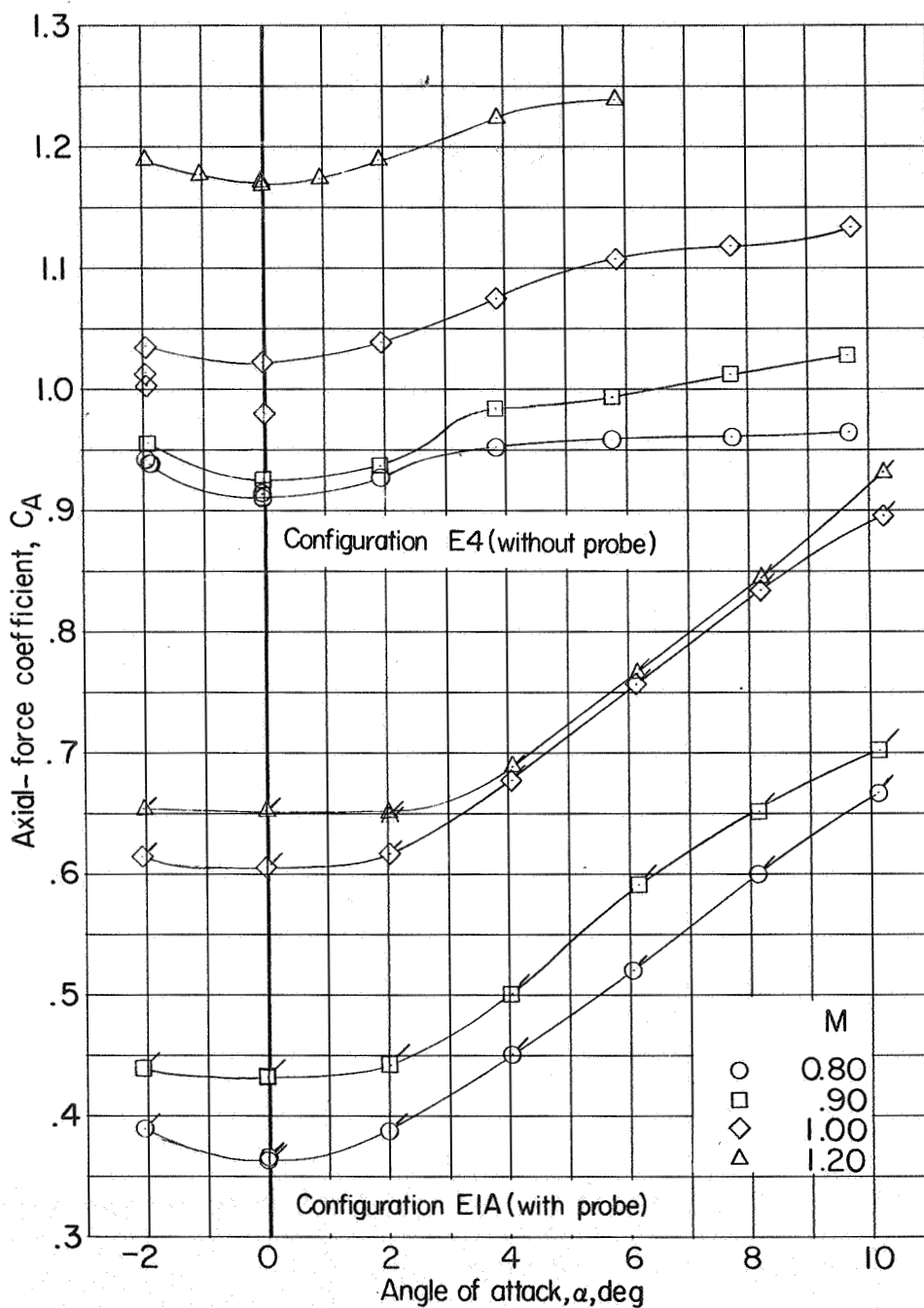


Figure 20.- Variation with angle of attack of axial-force coefficient for model configuration E1A with probe and E4 without probe. Plain symbols indicate data for model without probe, stagnation pressure is approximately 0.7 atmosphere; flagged symbols, model with probe, stagnation pressure is approximately 1.0 atmosphere.

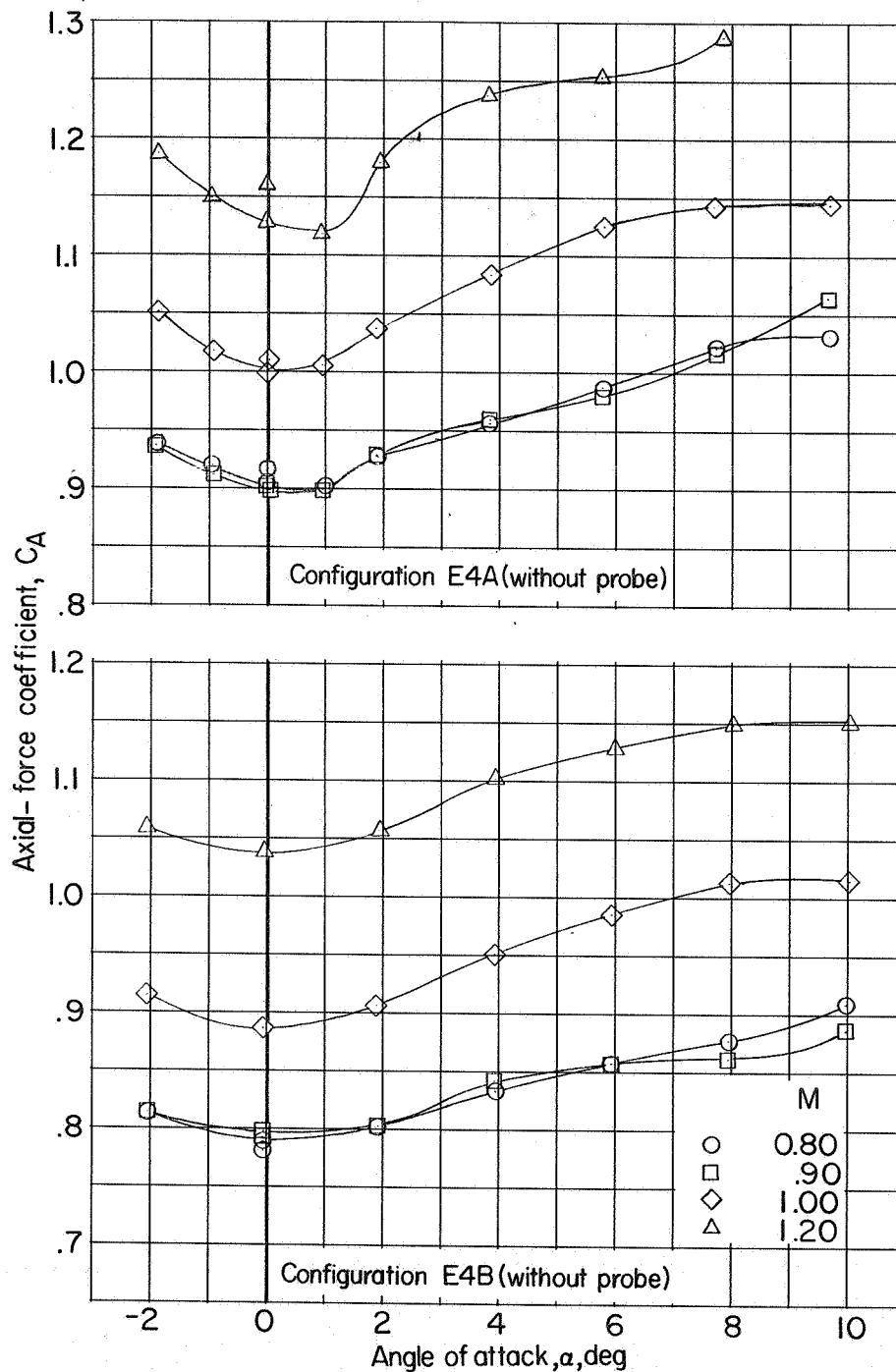


Figure 21.- Variation with angle of attack of axial-force coefficient for model configuration E4A and E4B without probe. Stagnation pressure is approximately 0.7 atmosphere.

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## ABSTRACT

The results of tests requested by the U. S. Army Ordnance on models of the T294, 90-millimeter shells are presented for Mach numbers of 0.8, 0.9, 1.0, and 1.2. The normal-force, axial-force, and pitching-moment characteristics of several configurations are presented for an angle-of-attack range of  $-2^{\circ}$  to  $10^{\circ}$ .

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